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# RADIATION CHARACTERISTICS OF A LINEAR ARRAY ANTENNA FOR A GROUND-WAVE RADAR AT A COASTAL SITE

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## ABSTRACT

The moment method is used to calculate the radiation pattern of a linear array for a number of array element configurations which include single monopole whips, single diamond shaped monopoles and three-element Yagi monopole whips over a perfect ground plane. Investigation of the far field radiation pattern is carried out for the cases of main lobe steering and pattern shaping ( using Tschebyscheff polynomial). The effect of varying the frequency on the radiation pattern is also studied. Results show that the linear array with Yagi monopole elements has larger gain and less reception from high altitudes than the linear array with quarter-wavelength monopole whips. Diamond-shaped monopoles have wider frequency band than the single whips, and their individual pattern may help suppress grating lobes in some higher frequency ranges.

## 1. Introduction

Detection and tracking of ships and icebergs is one of the important applications of ground wave radars in the area of ocean remote sensing. A long range radar system located at the coast uses a highly directional narrow beam for azimuthal directivity. To achieve this requirement a linear array is used where the half power beam width is equal to $50.4\lambda/L$ [1], where $\lambda$ is the wavelength and $L$ is array length. Usually, the array elements are quarter-wave length monopole whips over a ground plane. Some of the major problems that exist with this array design are the high level of interference which is due to receiving unwanted signals either from high altitudes or from the back of the array ( ground side ) and its relatively narrow band. Although the shape of the array element has no effect on the beam width, it is the dominant factor in achieving higher directivity, reduction of reception from high altitudes and in broadband operation. In the present work, the radiation patterns will be calculated for a number of array element configurations which include quarter-wavelength monopole whips and diamond shaped monopoles as shown in Fig. 1. In the study, the effects of adding one or two parallel excited and/or unexcited ( parasitic) identical arrays at $\lambda/4$ distance from the original array will be

investigated. Finally, the feasibility of using an optimal three element Yagi monopoles as array elements will be studied. Simplicity of construction and relatively high gain along its end-fire direction are some of the advantages of the Yagi antenna. Usually, the Yagi antenna is formed of a driver, and a reflector and/or a number of directors. Numerous graphical data [2] are available for investigating the effect of varying the Yagi's element diameter, element length, spacings between elements and overall length on the gain.

## 3. Array description

The array is formed of six elements with half wavelength separation over a perfect ground plane. The wavelength $\lambda$ is 44.444m corresponding to a frequency of 6.75MHz. The array is along the $y$ axis with broadside direction along the $x$ axis as shown in Fig. 2. The Numerical Electromagnetics Code (NEC) [3], which is based on the moment method is used to calculate the far field radiation pattern of the linear array. The single monopole whips are quarter-wave length and of $0.005\lambda$ diameter. The dimensions of the three element Yagi monopoles which will be used as array elements are such that the lengths of the reflector, driver and director whips are $0.2395\lambda$, $0.2265\lambda$, and $0.2255\ \lambda$, respectively [4]. The elements whose diameters are $0.005\lambda$ have equal spacing of quarter wavelength as shown in Fig. 3. The Yagis are positioned such that their endfire directions coincide with the broadside direction of the main array.

## 3. Discussion of numerical results

The study includes the calculation of the array radiation patterns for i) single monopole whips, ii) an identical parasitic grounded element at $\lambda/4$ from the element, iii) an identical excited element at $\lambda/4$ and iv) two identical parasitic elements placed at $\lambda/4$ from the element. All additional elements are placed along the broadside direction. The radiation patterns for the above cases are calculated and recorded in Table 1 when the basic element is either a diamond monopole ( shown in Fig. 1 ) or a $\lambda/4$ monopole whip. It is noticed that although the presence of a parasite array behind the excited array with whips improves the forward to back lobe ratio to 29.74dB, no appreciable improvement is observed in the reception from high angles at $39^{\circ}$ as shown in Table 1. Presence of two parasite arrays in front of and behind the array of diamond monopoles improves the high altitude reception ( from $42^{\circ}$ to $24^{\circ}$ )but at the expense of the front to back lobe ratio.

Also, two investigations of the radiation pattern will be carried out on the linear array with the Yagi whip elements; i) for various frequencies, and ii) for steering the main lobe of either a phased array (equal amplitude excitation) or a shaped pattern array ( a Tschebyscheff amplitude distribution, 1:2.3:3:3:2.3:1, with a side lobe level of -30dB). Figure 4 shows the

polar plots of the far field radiation patterns for the six element linear phased array in two cases of element configurations; quarter-wavelength single monopole whips and three element Yagis. The plots which contain both the E-plane and H-plane electric fields show the advantages of the array with Yagi elements over that with single whips. These advantages include higher H-plane gain ( 18.03B compared to 14.13dB ), narrower E-plane half power beam width for the monopole ( 25° compared to 38.5° ) and a larger front-to-back lobe ratio ( 7.8 dB in comparison to unity ). A study of the effect of frequency variation on the radiation pattern has been carried out around the design frequency of 6.75MHz. It is found that the maximum overall gain which coincides with the maximum H-plane gain, decreases steadily as the frequency falls below the design frequency. When the frequency exceeds the design value, the maximum overall gain starts having a vertical component, thus tilting up the main lobe. The E-plane half power beam width which is narrowest at the design frequency ( 25° at 6.75MHz ) widens with increasing frequency as illustrated in table 2.

At the design frequency, the radiation pattern was calculated for the case of steering the array main lobe to 60° from the broadside direction as a phased array or as shaped beam array. It is found that the main beam becomes directed towards 50° rather than the designed direction of 60°. This lag in steering can be understood using pattern multiplication as the Yagi elements H-plane radiation pattern is not uniform, unlike the single monopole whips.

## 4. Conclusion

The far field radiation patterns of a linear array for a number of elements' geometrical configurations have been investigated. Broadband operation of the array around the design frequency of 6.75MHz, is easily achieved with a diamond-shaped element ( shown in Fig. 1 ) rather than with quarter-wavelength monopole whips. A back parasitic array creates a forward to back lobe ratio resulting in reduction of noise from the back of the receiving array. In the case of diamond elements, reduction of high altitude reception requires the insertion of a second parasitic array in front of the array. In the case of whips, an optimal three- element Yagi is recommended. Over a narrow band, using a Yagi as an array element rather than quarter-wavelength single monopole whips results in higher overall gain ( increase signal to noise ratio), reduction in high altitude gain and large front-to-back lobe ratio ( reduction in interference and noise).

## References


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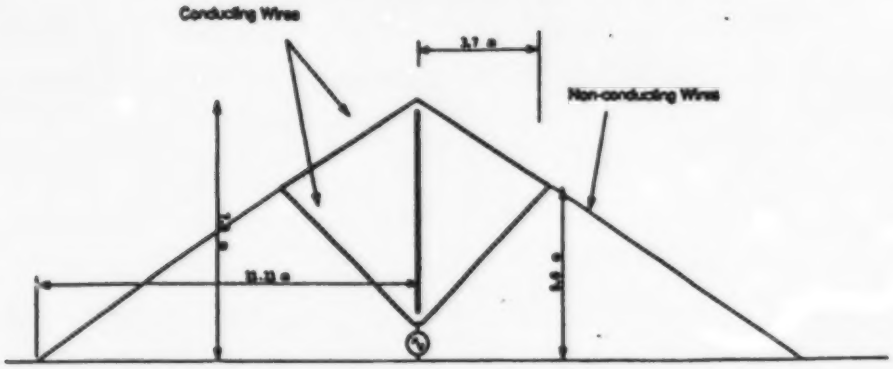


Fig. 1. Diamond-shaped monopole over a ground plane

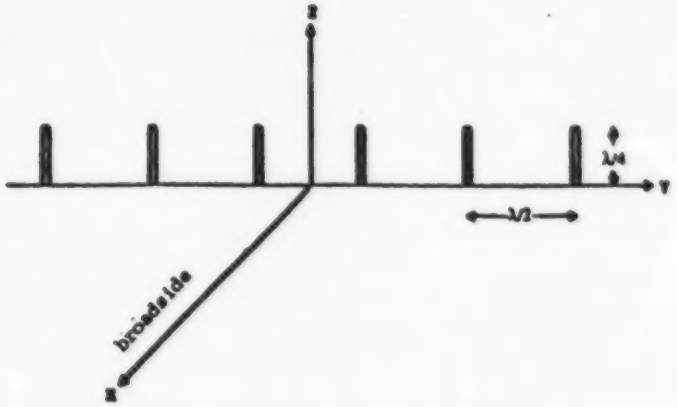


Fig. 2. Six quarter-wavelength monopoles linear array

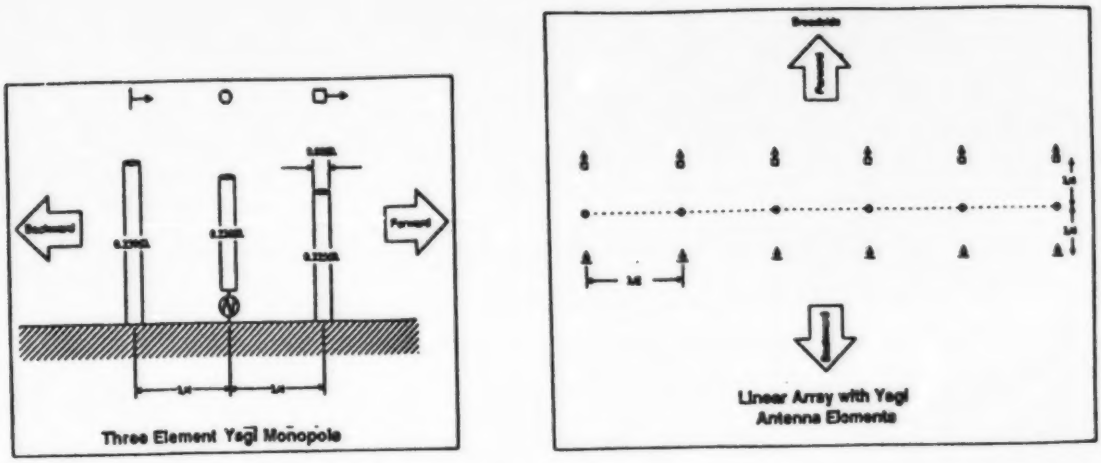


Fig. 3. Linear array with Yagi elements.

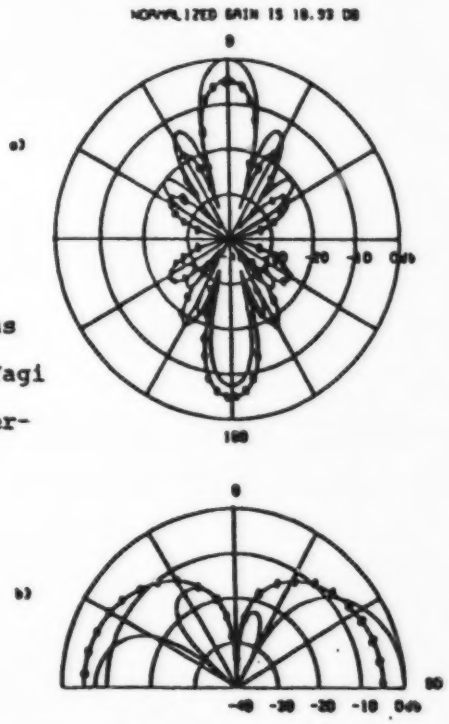

Fig. 4. Far field a) H-plane and E-plane radiation patterns for a linear array with Yagi elements (——) and quarter-wavelength whips (—●—)

Table 1. Radiation pattern for a six-element phased monopole array over perfect ground at different cases of elements configurations

| type of elements | H-plane directivity in dB | H-plane half power beam width in degrees | side lobes angle (degrees) | side lobes level (dB) | E-plane half power beam width in degrees |
|---|---|---|---|---|---|
| single whip | 14.13 | 18 | 30 | -13.37 | 39 |
| 2* | 17.14 (-29.74) | 17.4 | 30 | -13.05 | 38 |
| 3* | 13.71 (-1.54) | 18 | 30 | -12.03 | 46.5 |
| 4** | 8.17 | 13 | 24 | -9.8 | 19 |
| single diamond | 13.85 | 18.6 | 29 | -12.27 | 42 |
| 2* | 16.88 (-5.72) | 17 | 28 | -12.65 | 36 |
| 3 | 12.79 | 17 | 30 | -11.47 | 53 |
| 4 | 16.96 | 16 | 26 | -14.44 | 23.5 |

case 2 : a grounded parasitic identical element is placed $\lambda/4$ behind the element

case 3 : an identical element is placed $\lambda/4$ behind the element

case 2 : two grounded parasitic identical elements are placed, $\lambda/4$ apart from the main element and along the broadside direction of the array.

* : There is a front to back ratio which is given in parentheses.

** : The max. gain of 12.71 dB is tilting upward with an angle 53° from horizontal

Table 2. Variation of Radiation pattern Characteristics with frequency of a phased array with Yagi elements directed toward broadside. Respective values for the case when the elements are quarter-wave monopole whips are shown between parentheses.

| freq. in MHz | H-plane directivity in dB | front-to-back gain ratio in dB | H-plane half power beam width in degrees | side lobe level in dB | E-plane half power beam wid in degrees |
|---|---|---|---|---|---|
| 4.50 | 13.56 (13.17) | -0.28 (0.0) | 26 (26) | -12.72 (-12.17) | 40 (42) |
| 5.25 | 13.48 (12.90) | -0.20 (0.0) | 22 (22) | -13.13 (-12.20) | 37 (41) |
| 6.00 | 15.30 (13.33) | 1.17 (0.0) | 19 (19) | -13.67 (-12.05) | 31 (40) |
| 6.75 | 18.93 (14.13) | 7.57 (0.0) | 16 (18) | -13.29 (-13.37) | 25 (38.5) |
| 7.50* | 10.83 (14.75) | -11.95 (0.0) | 15.5 (16) | -9.62 (-13.14) | 41 (37) |
| 8.25* | 13.17 (15.26) | -1.43 (0.0) | 13 (14) | -13.62 (-12.90) | 36.5 (33.5) |
| 9.00 | 14.17 (15.77) | -0.27 (0.0) | 12.5 (13) | -12.59 (-13.01) | 51.5 (33) |